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SUMMARY REPORT

for

NAS10-8375

entitled

VOLTAGE PROFILE PROGRAM

for the

KENNEDY SPACE CENTER ELECTRIC POWER

DISTRIBUTION SYSTEM

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I. Introduction

The Kennedy Space Center Voltage Profile Program is designed to compute voltages at all busses greater than 1 Kv in the network under various conditions of load. The computation is based upon power flow principles and utilizes a Newton-Raphson iterative load flow algorithm. Consequently, power flow conditions throughout the network are also provided.

The Voltage Profile Program network data base is common to that employed in the Short Circuit Program. The additional data required is that which specifies bus loads. Therefore, only load representation is discussed in this report. Network bus codes and line data are given in the previous report entitled NETWORK MODEL and SHORT CIRCUIT PROGRAM for the KENNEDY SPACE CENTER ELECTRIC POWER DISTRIBUTION NETWORK. Certain assumptions have been made with regard to load profile and operational procedures employed. These are documented in Section II of the report.

The computer program is designed to operate in two modes; steady state operation and transient operation. In the steady state mode, automatic tap changing of primary distribution transformers is incorporated. Under transient conditions, such as motor starts etc., it is assumed that tap changing is not accomplished so that transformer secondary voltage is allowed to sag. Details of operation of the program are given in Section III of the report.

II. Load Estimation

A. General

Load estimation has been based on certain operational conditions of the Launch Complex and Industrial Area Networks already incorporated in both network models used with the Short-Circuit Programs; in the characteristics of the transformer substations (single or double-ended); in the nature of the load being served; and in special motor operation assignments.

Power transformers in Substations C-5 and Orsino have been considered with a regulated voltage output of 13.8 Kv and 13.2 Kv respectively, with Florida Power and Light Company voltage fluctuations at the 115 Kv bus within the regulation range. This is accomplished in the program by initially setting to 1.0 per unit the voltage at the Main Industrial (Launch Complex Bus Code A9; Industrial Area Bus Code H2008 and H2009). and Instrumentation Busses (Launch Complex Bus Code A8; Industrial Area Bus Code H2011). The voltage profile is then calculated for the network with steady loads only (transformer loads and motor operating loads). The transformer taps for this set of conditions are calculated. These taps are then set at the calculated values and another voltage profile is calculated for the total load (steady loads plus motor starting loads). This method of calculation takes into account the fact that tap changing transformers will not react rapidly enough to counteract transient voltage drops due to motor starting.

The Voltage Profile Program utilizes the network data tape prepared by the Short-Circuit Program. This eliminates the need for storing redundant data for the two programs. This feature has the added advantage that all impedances for the Industrial Area have been converted to the proper 13.2 Kv base by the Short-Circuit Program. This allows all voltage sources to be expressed as 1.0.

B. Operational Conditions Previously Included Into The Network Model

(a) Launch Complex

1. Four 10/14 MVA power transformers connected to Industrial bus 9; two 2.5/2.8 MVA transformers connected to Instrumentation bus 8.

2. Feeder #606 prefered Feeder for Pad A; Feeder #612 prefered Feeder for Pad B.

3. All emergency sources disconnected; all tie CB and tie normally opened switches "open."

4. All transformers served by switching stations #726, #727, #728, #743, #744, #745, and #773 normally connected to instrumentation Feeders #517 & #520; switching station #744 transformers connected to Industrial Feeder #607.

5. Switching station #728 Industrial bus connected to Feeder #610; Feeder #607 "open." Switching station #742 bus connected to Feeder #613; Feeder #604 open.

6. Mobile Launch Substation #928 connected to Pad A Feeders #518 & #606; Mobile service structure substation #923 connected to Pad A Feeders #606 & #612. All other connections to both substations "open."

(b) Industrial Area

1. Two 10/12.5 MVA power transformers connected to Industrial bus 2008; busses 2008 & 2009 normally closed; two 2.5/3.125 MVA power transformers connected to instrumentation bus 2011; critical bus 2100 normally closed to Instrumentation Bus 2011.

2. All emergency sources disconnected; interconnection between Launch Complex and Industrial Area Systems through 3-167 KVA 13.2/13.8 Kv voltage regulators open at LBS #301 (bus 2915), closed at LBS #47 (bus 2914); all oil circuit reclosures (Feeders #201, #206, #208, & #211) considered closed forming a loop to the fluid test area.

3. CIF FACILITY connected to Feeder #208 through LBS #60 & LBS #5 closed; Feeder #207 open at LBS #45 position #4 (bus code 2918). CIF ANTENNA SITE connected to Feeder #207 through LBS #45 except 300 KVA transformer which is connected to instrumentation Feeder #103 (bus code 2516) through LBS #72. Tie Feeder #209-207 open at LBS #45 position #3 (bus code 2903).

4. O & C building area connected to Feeder #204 through LBS #18 (bus 2395), except substation "A" connected to Feeder #202 thru LBS #19 (bus 2080) Feeder #203 open at LBS #19 (bus 2908). Feeder #202 open at LBS #13 (bus 2910).

5. Feeder #208 open at LBS #6 (bus code 2901), Tie Feeder with LBS #5. Feeder #209 open at LBS #2 (bus code 2902), Tie Feeder with LBS #4.

6. Feeder #205 open at LBS #18 (bus code 2906) and at LBS #15 (bus code 2911); Feeder #204 open at LBS #14 (bus code 2912) and at LBS #16 (bus code 2913); Feeder #212 open at LBS #15 (bus code 2083); Feeder #202 open at LBS #18 (bus code 2907) Tie Feeder to LBS #19.

7. Manned Space Craft Operations (substations CRA, CRB, CRC, & CRD) connected to critical Feeder #101; Feeder #103/102 tie to LBS #17 open at LBS #62 (bus code 2904); substation CRC closed to Feeder #103 (bus code 2905) thru LBS #29.

C. Operational Conditions Introduced For The Voltage Profile Program

.9 PF at every substation not serving 100% motor loads

(a) Launch Complex

1. All double ended substations with tie CB (open) in Pad "A" with a total load of 65% of the total capacity in transformation; each transformer loaded at 65% of its normal rating, such that on 1st contingency (one primary substation Feeder out of service) one transformer will serve the whole substation at 130% of its nominal rating.

2. All Pad "A" double ended substations without a tie CB (operating with both transformers energized and only one transformer main CB closed), the transformer supplied by Feeder #606 (assumed prefered) loaded at 100% of its normal rating, the second transformer considered unloaded (secondary main CB open).

3. Substations #928 (Mobile Launch) and #923 (Mobile Service Structure) each loaded at 50% of its transformation capacity.

4. All emergency connected single ended substations loaded at 100% of transformer rating.

5. All CCF & VAB area double ended substation transformers loaded at 50% of their rating with tie CB open.

6. LCC substation transformers loaded at 65% of rating as substation VABR #833 and Utility Annex #830.

7. Substations serving specificially motor loads as #829 (Utility Annex), #924 (Lox Pumps), & #927 (Boost Pump) have not been assigned any particular loading, instead motor operation is considered separately.

8. All Pad "B" substations open (Pad "B" not in use).

A list of substation transformers bus codes and estimated load factors follows:

Bus Code From	Bus Code To	MVA p.u.	Load Factor
H2381	D2382	.03	.5
H2383	D2384	.03	.5
H2385	D2386	.03	.5
H2387	C2388	.05	.5
H2389	D2390	.03	.5
H2431	C2432	.03	.65
H2433	D2434	.0225	.5
H2435	C2436	.05	.65
H2437	D2438	.015	.5
H2439	D2440	.05	.75
H2441	D2442	.05	.75
H2443	C2444	.075	.75
H2445	D2446	.05	.5
H2447	D2448	.01125	.5
H2447	K2449	.0015	.5
H2463	D2464	.0225	.2
H2465	C2466	.05	.2
H2467	C2468	.1	.75
H2469	C2470	.05	.65
H2475	C2476	.05	.65
H2478	C2479	.15	.65
H2481	C2482	.25	.65
H2504	D2505	.03	.65
H2506	D2507	.03	.65
H2508	D2509	.03	.65
H2510	D2511	.05	.65
H2517	D2513	.03	.65
H2524	D2525	.0225	.5
H2526	D2527	.075	.65
H2528	D2529	.075	.65
H2530	C2531	.03	.65
H2532	C2533	.03	.65
H2534	D2535	.0075	.65
H2539	C2750	.1	.65
H2852	C2853	.01125	.5

Assigned Load Factors

.65 ⟶ Double ended substation on main loads

.5 ⟶ Single substations

.75 ⟶ 1Ø transformers

Launch Complex Bus Code

Bus Code From	Bus Code To	MVA p.u.	Load Factor
A12	C13	.03	.65
A14	C305	.03	.65
A16	C17	.05	.5
A22	C34	.1	.5
A23	C37	.15	.5
A24	C41	.075	.5
A25	C42	.1	.65
A26	C309	.1	.5
A27	C307	.1	.5
A28	C308	.15	.5
A29	C310	.1	.65
A33	C36	.075	.5
A35	C316	.075	.5
A38	C40	.1	.5
A39	C317	.1	.5
A44	C50	.075	.65
A51	C306	.075	.65
A53	C55	.15	.65
A54	C311	.15	.65
A60	C182	.0075	1.
A61	C210	.0225	1.
A64	C93	.01125	1.
A66	C94	.0045	1.
A67	C95	.0045	1.
A71	C96	.03	1.
A72	C97	.0045	1.
A73	C191	.0225	1.
A74	C189	.0045	1.
A75	C187	.03	1.
A79	C196	.0045	1.
A80	C194	.0045	1.
A81	C207	.03	1.
A84	C202	.0045	1.
A85	C204	.0225	1.
A88	C92	.1	.65
A91	C318	.1	.65
A119	C319	.05	.5
A122	C123	.05	.5
A125	C312	.1	.5
A126	C313	.15	.5
A127	C314	.075	.5
A128	C315	.1	.5
A129	C133	.1	.5
A130	C134	.15	.5
A131	C135	.075	.5
A132	C136	.1	.5
A137	C143	.1	.5

Launch Complex Bus Code

Bus Code From	Bus Code To	MVA p.u.	Load Factor
A138	C320	.1	.5
A139	C321	.1	.5
A140	C144	.1	.5
A141	C145	.1	.5
A142	C322	.1	.5
A147	D212	.0225	.5
A151	C156	.05	.5
A152	C323	.05	.5
A153	C157	.15	.5
A154	C324	.15	.5
A168	C172	.015	.75
A169	C171	.0225	.75
A174	C176	.1	.75
A175	D177	.03	1.
A188	C186	.0225	1.
A199	C200	.03	1.
A211	C213	.075	.75
A214	C215	.2	.5
A216	C217	.2	.5
A218	C219	.2	.5
A220	C221	.15	.75
A223	C227	.075	open
A224	C190	.075	1.
A229	C230	.03	.75
A231	C232	.3125	1.
A235	C234	.03	.75
A236	C237	.2	.65
A238	C185	.2	.65
A239	C241	.03	1.
A242	C195	.1	1.
A250	C292	.075	1.
A255	D256	.03	.75
A261	C293	.2	1.
A290	C253	.05	1.
A325	C258	.25	.65
A326	C260	.2	1.
A340	D180	.0225	1.
A341	C173	.01125	.75
A342	C170	.0225	.75
A353	C259	.1	1.
A208	C209	.0045	1.
Normally Open Transformers			
A233	C329	.2	open
A240	C184	.075	open
A244	C243	.1	open
A251	C291	.05	open
A252	C254	.075	open

Launch Complex Pad "B" Normally Open When Pad "A" "ON"

Bus Code From	Bus Code To	MVA p.u.	Load Factor
A265	C266	.2	.65
A267	C294	.2	.65
A268	C269	.075	1.
A271	C270	.075	1.
A272	C273	.05	open
A274	C295	.05	.75
A275	C276	.03	1.
A278	C277	.25	.65
A279	C296	.25	.65
A280	C281	.15	.65
A283	C282	.15	.65

(b) Industrial Area

It follows a list of estimated loads and substations bus codes based on the criteria:

1. Single ended substations to be loaded at 50% of transformer capacity.

2. Single phase transformer loaded at 75% of its rating.

3. Double ended substations or substations serving important loads with transformers loaded at 65% of their capacity.

4. Substations serving 2300V Chillers (CIF bus codes 2272-2273 & 2034-2274, OA bus codes 2296-2297 & 2295-2298, "B" bus codes 2473-2474, "C" bus codes 2471-2472) have not been assigned any particular loading, instead motor operation conditions have been considered separately.

Industrial Area

Bus Code From	Bus Code To	MVA p.u.	Load Factor
H2030	C2095	.075	.65
H2033	C2190	.0075	.75
H2034	C2275	.2	.65
H2034	D2276	.1	.65
H2034	D2277	.1	.65
H2036	C2512	.075	.65
H2036	D2515	.0225	.65
H2038	C2254	.075	.5
H2040	C2252	.05	.65
H2041	C2253	.05	.65
H2043	C2251	.0225	.75
H2044	C2250	.05	.75
H2046	C2255	.075	.65
H2047	C2256	.075	.65
H2049	C2810	.015	.5
H2052	C2257	.03	.5
H2054	C2258	.0225	.75
H2056	C2259	.1	.65
H2058	D2260	.015	.75
H2059	D2227	.0075	.75
H2061	C2454	.015	.75
H2062	K2455	.0015	.5
H2064	D2453	.01125	.5
H2066	C2452	.03	.5
H2067	C2451	.03	.5
H2068	C2450	.03	.5
H2069	C2261	.01125	.5
H2072	D2262	.0045	.5
H2073	C2263	.03	.5
H2074	C2264	.03	.5
H2076	D2265	.03	.5
H2077	D2266	.01125	.5
H2084	C2480	.15	.65
H2085	C2477	.25	.65
H2093	2772	.05	.75
H2094	C2092	.075	.75
H2170	K2171	.0015	.75
H2174	K2175	.0015	.75
H2176	K2177	.0015	.75
H2180	K2181	.0015	.75
H2182	K2183	.0015	.75
H2184	K2185	.00375	.75
H2186	D2187	.0075	.75
H2188	C2189	.050	.65
H2191	C2192	.01125	.75
H2193	D2194	.0075	.75
H2195	D2196	.01125	.65
H2208	C2209	.015	.5
H2217	D2179	.0045	.75

Bus Code From	Bus Code To	MVA p.u.	Load Factor
H2218	D2219	.0075	.75
H2220	C2221	.01	.75
H2222	K2223	.0025	.75
H2224	K2225	.0015	.75
H2224	D2226	.0075	.75
H2228	D2229	.05	.65
H2230	C2231	.03	.65
H2230	C2232	.05	.65
H2233	D2234	.05	.65
H2233	C2235	.05	.65
H2236	D2239	.1	.65
H2237	C2238	.15	.65
H2237	C2240	.075	.65
H2241	C2242	.01125	.65
H2281	D2282	.1	.65
H2283	D2284	.1	.65
H2285	D2286	.1	.65
H2299	D2300	.05	.5
H2301	C2302	.075	.5
H2303	D2304	.05	.5
H2305	D2306	.0225	.5
H2307	C2308	.05	.5
H2309	D2310	.015	.5
H2311	D2312	.015	.5
H2313	D2314	.015	.5
H2315	C2316	.03	.5
H2317	C2318	.075	.5
H2319	C2320	.05	.5
H2321	D2322	.05	.5
H2323	D2324	.03	.5
H2325	D2326	.03	.5
H2327	C2328	.03	.5
H2329	D2330	.03	.5
H2331	D2332	.05	.5
H2333	D2334	.05	.5
H2353	D2354	.03	.5
H2355	C2356	.03	.5
H2357	D2358	.03	.5
H2359	D2360	.03	.5
H2361	D2362	.03	.5
H2363	D2364	.03	.5
H2365	D2366	.03	.5
H2367	D2368	.03	.5
H2369	C2370	.05	.5
H2371	D2372	.03	.5
H2373	D2374	.03	.5
H2375	D2376	.03	.5
H2377	C2378	.05	.5
H2379	D2380	.03	.5

D. Motor Loads

All motor loads specifically considered are 4160V and 2300V motors in the Launch Complex and Industrial Area Systems respectively. All these motors have been considered to have a reactor or autotransformer type reduced voltage starter connected at the 80% tap.

Starting inrush currents consequently have been modeled as a 3Ø bolted short-circuit through an impedance equal to 125% of the positive-sequence motor reactance. Running conditions have been represented as MVA per unit at .85 power factor.

(a) Launch Complex

List of motor loads at 4.16 Kv (nominal)

Bus Code	MVA p.u.	PF	Location
B102	.02808	1.0	350 HP Synchronous Air Compressor Motor #2 at Utility Annex MCC-A
B103	.02808	1.0	350 HP Synchronous Air Compressor Motor #1 at Utility Annex MCC-A
B104	.2016	1.0	2500 HP Synchronous Refrigerator #3 at Utility Annex MCC-A
B105	.2016	1.0	2500 HP Synchronous Refrigerator #4 at Utility Annex MCC-A
B106	.04572	.85	450 HP Induction Condensate Water Pump #4 at Utility Annex MCC-B
B108	.05328	.85	550 HP Induction Condensate Water Pump #3 at Utility Annex MCC-B
B109	.04572	.85	450 HP Induction Condensate Water Pump #2 at Utility Annex MCC-B
B110	.04572	.85	450 HP Induction Condensate Water Pump #1 at Utility Annex MCC-B
B111	.2016	1.0	2500 HP Synchronous Refrigerator #2 at Utility Annex MCC-B
B112	.2016	1.0	2500 HP Synchronous Refrigerator #1 at Utility Annex MCC-B
B113	.0414	.85	450 HP Induction Chilled Water Pump #3 at Utility Annex MCC-B

Bus Code	MVA p.u.	PF	Location
B114	.0414	.85	450 HP Induction Chilled Water Pump #2 at Utility Annex MCC-B
B115	.0414	.85	450 HP Induction Chilled Water Pump #1 at Utility Annex MCC-B
B334	.21384	.85	2500 HP Induction Lox Pump at Substation #1021-1
B335	.017352	.85	200 HP Induction Lox Pump at Substation #1021-1
B337	.21384	.85	2500 HP Induction Lox Pump at Substation #1021-2
B338	.017352	.85	200 HP Induction Lox Pump at Substation #1021-1
B351	.0864	.85	1000 HP Induction ML Water Pump at Substation #1020
B343	.0864	.85	1000 HP Induction ML Water at Substation #927
B344	.04392	.85	500 HP Induction Firex Pump at Substation #927
B347	.21384	.85	2500 HP Induction Lox Pump #1 at Substation #924-1
B348	.017352	.85	200 HP Induction Lox Pump #2 at Substation #924-1
B349	.21384	.85	2500 HP Induction Lox Pump #2 at Substation #924-2
B350	.02628	.85	300 HP Induction Lox Pump #1 at Substation #924-2
B352	.035424	.85	400 HP Induction Firex Pump at Substation 1020

(b) Industrial Area

List of motor loads at 2.3 Kv (nominal)

Bus Code	MVA p.u.	PF	Location
J2271	.0593	.85	CIF-Chiller #1, 650 HP - 149 FLA
J2271	.0593	.85	CIF-Chiller #2, 650 HP - 149 FLA
J2289	.0593	.85	CIF-Chiller #3, 650 HP - 149 FLA
J2350	.0824	.85	Substation "OA"-Chiller #120, 700 HP - 207 FLA
J2351	.0824	.85	Substation "OA"-Chiller #103, 700 HP - 207 FLA
J2352	.0748	.85	Substation "OA"-Chiller #101, 700 HP - 188 FLA
J2496	.0679	.85	Substation "B"-Chiller # 1, 650 HP - 171 FLA
J2497	.0679	.85	Substation "B"-Chiller # 2, 650 HP - 171 FLA
J2499	.0679	.85	Substation "C"-Chiller # 3, 650 HP - 171 FLA
J2500	.0679	.85	Substation "C"-Chiller # 4, 650 HP - 171 FLA

MVA Base = 1.0 = 10MVA

II. Voltage Profile Program

A. Introduction

The KSC voltage profile program will be discussed in the following paragraphs. The approach taken will be to describe first the basic computational procedure and then the details of the program structure. The discussion will be user-oriented with emphasis placed on program utilization.

The voltage profile program will calculate the voltage profile and power flows of the KSC high voltage network for any given load pattern. The computational procedures utilized are based on essentially standard techniques employed in power industry load flow programs. A more detailed discussion of the principles employed can be found in the book "Computer Methods in Power System Analysis" by Glenn W. Stagg and Ahmed H. El-Abiad. To reduce the mass storage required, the program utilizes sparse matrix techniques with an optimal numbering algorithm specifically designed for the radial structure of the KSC network.

B. Voltage Profile Calculations

(a) General Description

The voltage profile program utilizes the Y_{Bus} network formulation. Using the bus frame of reference, the network is described by

$$\bar{I}_{Bus} = Y_{Bus} \bar{E}_{Bus} \qquad (2.1)$$

The real and reactive power at any bus "p" is

$$P_p - jQ_p = E_p^* I_p \qquad (2.2)$$

The real and reactive power flow in a line joining bus "p" to bus "q" can be calculated as

$$P_{pq} - jQ_{pq} = E_p^* (E_p - E_q) \, y_{pq} \qquad (2.3)$$

Due to the non-linearity of the above set of equations, the solution of these equations is based on an iterative technique. The technique used by the KSC voltage profile program is the Newton-Raphson method. The solution must satisfy Kirchhoff's laws. The test for convergence of the method is that the currents satisfy Kirchhoff's current law.

(b) Deriving the Jacobian

If the network performance equation (2.1) is substituted for I_p in equation (2.2)

$$P_p - jQ_p = E_p^* \sum_{q=1}^{n} y_{pq} E_q \qquad (2.4)$$

Since $E_p = e_p + jf_p$ and $y_{pq} = g_{pq} - jb_{pq}$ equation (2.4) can be separated into real and imaginary parts.

$$P_p = \sum_{q=1}^{n} (e_p(e_q g_{pq} + f_q b_{pq}) + f_p(f_q g_{pq} - e_q b_{pq}))$$

$$Q_p = \sum_{q=1}^{n} (f_p(e_q g_{pq} + f_q b_{pq}) - e_p(f_q g_{pq} - e_q b_{pq}))$$

$$(2.5)$$

This formulation results in 2n nonlinear simultaneous equations. One bus must be designated as the slack bus. The slack bus provides the additional real and reactive power to supply the transmission losses. At this bus the voltage magnitude and phase angle are specified. (In the KSC program these are 1.0 and 0.0 respectively). The real and reactive powers, P_p and Q_p, are specified for all buses except the slack bus. Thus, there are 2n simultaneous equations with 2n unknown variables. The equations for real and reactive power at the slack bus can be separated from the remaining equations. This leaves a system of 2(n-1) simultaneous nonlinear equations to be solved for e and f at all buses except the slack bus. Once all the bus voltages are calculated, the slack bus real and reactive power can be calculated directly.

The system of nonlinear simultaneous equations is solved by the Newton-Raphson method. The Newton-Raphson method requires that a set of linear equations be formed expressing the relationship between changes in real and reactive powers and the components of bus voltages.

$$\begin{bmatrix} \Delta P_2 \\ \cdot \\ \cdot \\ \Delta P_n \\ \hline \Delta Q_2 \\ \cdot \\ \cdot \\ \Delta Q_n \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\delta P_2}{\delta e_2} & \cdots & \frac{\delta P_2}{\delta e_n} & \frac{\delta P_2}{\delta f_2} & \cdots & \frac{\delta P_2}{\delta f_n} \\ \cdot & & \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot & & \cdot \\ \frac{\delta P_n}{\delta e_2} & \cdots & \frac{\delta P_n}{\delta e_n} & \frac{\delta P_n}{\delta f_2} & \cdots & \frac{\delta P_n}{\delta f_n} \\ \hline \frac{\delta Q_2}{\delta e_2} & \cdots & \frac{\delta Q_2}{\delta e_n} & \frac{\delta Q_2}{\delta f_2} & \cdots & \frac{\delta Q_2}{\delta f_n} \\ \cdot & & \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot & & \cdot \\ \frac{\delta Q_n}{\delta e_2} & & \frac{\delta Q_n}{\delta e_n} & \frac{\delta Q_n}{\delta f_2} & & \frac{\delta Q_n}{\delta f_n} \end{array}\right] \begin{bmatrix} \Delta e_2 \\ \cdot \\ \cdot \\ \Delta e_n \\ \hline \Delta f_2 \\ \cdot \\ \cdot \\ \Delta f_n \end{bmatrix} \tag{2.6}$$

The coefficient matrix in equation (2.6) is called the Jacobian. Bus 1 is considered the slack bus. This set of equations can be expressed in matrix form as

$$\begin{bmatrix} \Delta P \\ \hline \Delta Q \end{bmatrix} = \left[\begin{array}{c|c} J_1 & J_2 \\ \hline J_3 & J_4 \end{array}\right] \begin{bmatrix} \Delta e \\ \hline \Delta f \end{bmatrix} \tag{2.7}$$

This set of equations can easily be solved by matrix inversion.

$$\begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{2.8}$$

Therefore, given an initial set of bus voltages, the real and reactive powers are calculated from equation (2.5). The changes in power are the differences between scheduled and calculated values.

$$\Delta P_p = P_p \text{ (scheduled)} - P_p \text{ (calculated)}$$

$$\Delta Q_p = Q_p \text{ (scheduled)} - Q_p \text{ (calculated)} \tag{2.9}$$

The initial set of bus voltages are also necessary to calculate the elements of the Jacobian.

$$J_1 = \begin{bmatrix} \frac{\delta P_2}{\delta e_2} & \cdots\cdots & \frac{\delta P_2}{\delta e_n} \\ \vdots & & \vdots \\ \frac{\delta P_n}{\delta e_2} & \cdots\cdots & \frac{\delta P_n}{\delta e_n} \end{bmatrix}$$

$$J_2 = \begin{bmatrix} \frac{\delta P_2}{\delta f_2} & \cdots\cdots & \frac{\delta P_2}{\delta f_n} \\ \vdots & & \vdots \\ \frac{\delta P_2}{\delta f_n} & \cdots\cdots & \frac{\delta P_n}{\delta f_n} \end{bmatrix}$$

$$J_3 = \begin{bmatrix} \frac{\delta Q_2}{\delta e_2} & \cdots\cdots & \frac{\delta Q_2}{\delta e_n} \\ \vdots & & \vdots \\ \frac{\delta Q_n}{\delta e_2} & \cdots\cdots & \frac{\delta Q_n}{\delta e_n} \end{bmatrix}$$

$$J_4 = \begin{bmatrix} \frac{\delta Q_n}{\delta f_2} & \cdots\cdots & \frac{\delta Q_2}{\delta f_n} \\ \vdots & & \vdots \\ \frac{\delta Q_n}{\delta f_2} & \cdots\cdots & \frac{\delta Q_n}{\delta f_n} \end{bmatrix} \tag{2.10}$$

The linear set of equations (2.7) can be solved by equations (2.8) for Δe_p and Δf_p, $p = 2, 3, . . . , n$. Then, the new estimates for bus voltage are

$$e_p' = e_p + \Delta e_p \tag{2.11a}$$

$$f_p' = f_p + \Delta f_p \tag{2.11b}$$

The process is repeated until ΔP_p and ΔQ_p for all buses are within a specified tolerance and $\sum_{k=2}^{n} |P_k|$ and $\sum_{k=2}^{n} |Q_k|$ are also within a specified tolerance.

The individual line flows can then be calculated from equation (2.3).

(c) <u>Representation of Tap Changing Transformers</u>

There are four quantities associated with each bus in the network: P, Q, e, and f. In the preceeding discussion P and Q are known for all buses except the slack bus. For the slack bus, e and f are known.

If an automatic tap changing transformer exists in the network, the quantities known for the transformer secondary are P and e. The unknown quantities are Q and f. The quantity e is known because the automatic tap changing transformer is set to hold e at some desired value. Q is unknown at this point since the desired tap setting is unknown, and thus the value of the shunt element in the transformer model is unknown. Therefore, if bus q represents the secondary of an automatic tap changing transformer, P_q and e_q are known and Q_p and f_q are unknown. The equations in the preceeding discussion must therefore be modified as follows:

In equations (2.7) and (2.8)

$$Q = \begin{bmatrix} \Delta Q_2 \\ \cdot \\ \cdot \\ \Delta e_q \\ \cdot \\ \Delta Q_n \end{bmatrix}$$

$$e = \begin{bmatrix} \Delta e_2 \\ \cdot \\ \cdot \\ \Delta Q_q \\ \cdot \\ \Delta e_n \end{bmatrix} \tag{2.12}$$

In equation (2.10)

$$J_1 = \begin{bmatrix} \frac{\delta P_2}{\delta e_2} & \cdots & \frac{\delta P_2}{\delta Q_q} & \cdots & \frac{\delta P_2}{\delta e_n} \\ \vdots & & \vdots & & \vdots \\ \frac{\delta P_n}{\delta e_2} & & \frac{\delta P_n}{\delta Q_q} & & \frac{\delta P_n}{\delta e_n} \end{bmatrix}$$

J_2 is unchanged

$$J_3 = \begin{bmatrix} \frac{\delta Q_2}{\delta e_2} & \cdots & \frac{\delta Q_2}{\delta Q_q} & \cdots & \frac{\delta Q_2}{\delta e_n} \\ \vdots & & \vdots & & \vdots \\ \frac{\delta e_q}{\delta e_2} & \cdots & \frac{\delta e_q}{\delta Q_q} & \cdots & \frac{\delta e_q}{\delta e_n} \\ \vdots & & \vdots & & \vdots \\ \frac{\delta Q_n}{\delta e_2} & \cdots & \frac{\delta Q_n}{\delta Q_q} & \cdots & \frac{\delta Q_n}{\delta e_n} \end{bmatrix}$$

$$J_4 = \begin{bmatrix} \frac{\delta Q_2}{\delta f_2} & \cdots & \frac{\delta Q_2}{\delta f_n} \\ \vdots & & \vdots \\ \frac{\delta e_q}{\delta f_2} & \cdots & \frac{\delta e_q}{\delta f_n} \\ \vdots & & \vdots \\ \frac{\delta Q_n}{\delta f_2} & \cdots & \frac{\delta Q_n}{\delta f_n} \end{bmatrix} \tag{2.13}$$

and equation (2.11b) becomes

$$f_p' = f_p + \Delta f_p, \quad p \neq q$$

$$Q_p' = Q_q + \Delta Q_q \tag{2.14}$$

(d) Representation of Motor Starting Loads

The previous discussion assumed that the automatic tap changing feature of certain transformers would hold the voltage magnitude at the transformer secondary constant. This assumption is valid for slowly varying or constant loads. However, for a large instantaneous load changes such as that

of motor starting, the transformer will not react rapidly enough to compensate for this additional load. The voltage profile program, therefore, has special provisions for motor starting loads. The program first calculates the voltage profile for the network using the method of section C above for all loads except the motor starting loads. This calculation will specify the transformer tap that the automatic tap changing transformer will be using prior to motor starting. The motor starting load is then added forming the total load pattern on the network. The voltage profile for the total load is calculated using the method of section B with the transformer tap as calculated.

C. Input Data Preparation

Two types of information are needed to calculate a voltage profile for a network. First, the network data is needed. The KSC Voltage Profile program uses the network data stored on tape by the KSC Short Circuit program. Second, load data must be gathered. The KSC Voltage Profile program calculates a voltage profile for the high voltage network only. Therefore, only the loads at the high voltage buses are required. The two types of loads considered by the program are transformer loads and motor loads.

A transformer load is a load on the high voltage network caused by a transformer which feeds the low voltage network. This load is represented by naming the bus in the high voltage network where the load is applied and determining the MVA load through the transformer and the power factor.

A motor load is a load on the network caused by a motor connected directly to the high voltage network. A motor in the "RUN" condition is represented by the MVA rating of the motor with an appropriate power factor. A motor in the "START" condition is represented by its transient impedance. A motor in the "STOP" condition is represented as no load.

The above data has been assembled for the KSC network in the current configuration using the assumptions outlined earlier in this report. It is recommended that where possible this data be updated as more information can be gathered by measurement and operating experience. The data provided in this report is a "best approximation" for the information currently available. The data must also be updated as the load pattern changes with new loads being added and old loads being deleted.

Since the voltage profile program uses the network data stored by the short circuit program, all bus/line additions/deletions must be made through the short circuit program. If a temporary addition/deletion is desired, the short circuit program can create a new tempory data tape for use by the voltage profile program. This process is described in the previous report SHORT CIRCUIT PROGRAM for the KENNEDY SPACE CENTER ELECTRIC POWER DISTRIBUTION NETWORK.

D. Program Utilization

The data is read into the program logical blocks. The blocks of information must be organized as follows:

Network
Data

P-V Bus
Names

Transformer
Data

Motor
Data

Each of these blocks will now be described:

(a) Network Data

This block contains only one card. This card will point the program to the exact location on tape where the network data is stored. This network data has been stored by the KSC Short Circuit program.

This card is formatted as follows:

Card Column	Field	Definition
1-10	IC4	FORTRAN I/O device number on which the history tape reel is mounted.
11-20	IC6	Record number which is to be loaded.

(b) P-V Names

This block contains the bus names of buses which represent the secondary of automatic tap changing transformers. One bus is named per card with the bus name appearing in the first six columns of the card. The last card in this block must be "*END" to signal the end of the block. For the network in the current configuration this block is as follows:

Launch Complex	Industrial Area
A8	H2011
A9	H2008
*END	*END

(c) Transformer Data

The third block contains the data for the transformer loads on the high voltage network. The data is presented with one transformer per card in the format below. The final card in this block must be *END.

Card Column	Field	Definition
1-6	NP	Bus name of high voltage bus where load is connected.
9-16	MVAPU	Magnitude of load in per unit. (MVA base for KSC is 10, therefore, this number is MVA load divided by 10).
17-23	PF	Power factor of load.

(d) Motor Data

The final block contains the data for the motor loads. The data is presented with one motor per card in the format below. The final card is this block must also be "*END".

Card Column	Field	Definition
1-6	NP	Bus name of high voltage bus where motor is connected.
9-16	MVAPU	Magnitude of load in per unit created by motor when running. (MVA rating of motor divided by 10)
17-27	PF	Power factor of running motor (can be estimated as 1.0 for synchronous motors and 0.85 for induction motors).
24-31	R	Real part of transient impedance in per unit.
32-39	X	Imaginary part of transient impedance (Transient reactance) in per unit. (R and X can be estimated as 125% of positive sequence motor reactance)
40-42	IC	Motor condition: 0 - stop 1 - run 2 - start

(e) Output Descriptio

On the output the network title from the Short Circuit program is printed at the top of each page along with the reference (slack) bus, the number of buses and lines in the network and the MVA base. The output is organized by buses. There will be a section of the output giving flows and voltages around each bus in the network. The name of the bus appears under "BUS NAME". To the right of the bus name appears the voltage at that bus and a space in which motor information may be printed. If no motor is attached to the bus, the motor field is blank.

Below the bus voltage is information about all lines connected to the bus. For each line the following information is printed: The name of the bus at the opposite end of the line, the voltage at the opposite end of the line, the line flow in per unit, the per unit line voltage drop, and the angular difference between the voltages at each end of the line. To obtain the actual line flow in megawatts and megavars multiply the numbers under P and Q by 10. The algebraic sign of P and Q determine the direction of line flow. For example, if the number .015 is found in the P column, there are .15 megawatts flowing from the bus named under "BUS NAME" to the bus under "OPPOSITE END BUS." However, if the number in the P column is -.015 then there is .15 megawatts flowing from the bus named as "OPPOSITE END BUS" to the bus named under "BUS NAME."

Below the line is printed the total load at the bus in per unit.

(f) Transient Fault Calculations

The voltage profile program may also be used for transient fault calculations. This information could easily be obtained from the Short Circuit Program; however, the more compact output of the voltage profile program may occasionally be desired. The voltage profile program can perform fault calculations with loads on the network. This can often be an advantage since conventional short cirucit programs neglect all loads on the system. The voltage profile program will also allow multiple faults.

Fault calculations are implemented with the voltage profile program by representing the fault as a motor starting. As discussed previously, the voltage profile program models motor start-up as a shunt impedance as given in the motor data cards in columns 24-31 (real) and 32-39 (imaginary). To place a fault on a given bus prepare a card with the

bus name in columns 1-6, the resistance value of the fault in per unit in columns 24-31, and a 2 in column 42. If the fault is a direct short, i.e. zero resistance, columns 24-31 may be left blank and zero will be assumed.

E. Examples

(a) Addition of a transformer

In this example a second transformer has been added at bus A353 in the Launch Complex. This transformer has a rating of 1 MVA. It is assumed that the transformer will operate at 50% of capacity with a power factor of .85.

To add this transformer to the network a card must be prepared with the bus name (A353) in columns 1-4, .05 in columns 9-11, and .85 in columns 17-19. Place this card in the load data deck for the Launch Complex. The card may be inserted anywhere within the block of transformer data cards.

(b) Removal of a transformer

In this example the transformer at bus A12 in the launch is removed. Referring to Appendix 1, note that the fifth card in the data card for the transformer located at bus A12. To remove the transformer from service, remove the load data card for this transformer.

(c) Motor starting

To calculate the voltage profile for the launch complex with the motor at B102 starting change the 1 in column 42 of the motor data card to a 2. Referring to Appendix 1, note that the motor data card for the motor at bus B102 is the first motor data card in the launch complex load data deck.

(d) Transient Fault

Transient faults may be placed in the network simultaneously at several buses. The following data deck will calculate the voltage profile for simultaneous faults at buses A223, A224, and A229 of the Launch Complex.

	Column Entry			
Card	col. 1-4	col. 10	col. 20	col. 42
1		2	1	
2	A8			
3	A9			
4	*END			
5	*END			
6	A223			2
7	A224			2
8	A229			2
9	*END			

APPENDIX A - DATA CARDS PROVIDED FOR LAUNCH COMPLEX

1		2	1
2	A8		
3	A9		
4	*END		
5	A12	.03	.65
6	A14	.03	.65
7	A16	.05	.5
8	A22	.1	.5
9	A23	.15	.5
10	A24	.075	.5
11	A25	.1	.65
12	A26	.1	.5
13	A27	.1	.5
14	A28	.15	.5
15	A29	.1	.65
16	A33	.075	.5
17	A35	.075	.5
18	A38	.1	.5
19	A39	.1	.5
20	A44	.075	.65
21	A51	.075	.65
22	A53	.15	.65
23	A54	.15	.65
24	A60	.0075	1.
25	A61	.0225	1.
26	A64	.01125	1.
27	A66	.0045	1.
28	A67	.0045	1.
29	A71	.03	1.
30	A72	.0045	1.
31	A73	.0225	1.
32	A74	.0045	1.
33	A75	.03	1.
34	A79	.0045	1.
35	A80	.0045	1.
36	A81	.03	1.
37	A84	.0045	1.
38	A85	.0225	1.
39	A88	.1	.65
40	A91	.1	.65
41	A122	.05	.5
42	A125	.1	.5
43	A126	.15	.5
44	A127	.075	.5
45	A128	.1	.5
46	A129	.1	.5
47	A130	.15	.5
48	A131	.075	.5
49	A132	.1	.5
50	A137	.1	.5
51	A138	.1	.5
52	A139	.1	.5
53	A140	.1	.5
54	A141	.1	.5
55	A142	.1	.5
56	A151	.05	.5

57	A152	.05	.5			
58	A153	.15	.5			
59	A154	.15	.5			
60	A168	.015	.75			
61	A169	.0225	.75			
62	A174	.1	.75			
63	A175	.03	1.			
64	A199	.03	1.			
65	A208	.0045	1.			
66	A211	.075	.75			
67	A214	.2	.5			
68	A216	.2	.5			
69	A218	.2	.5			
70	A220	.15	.75			
71	A223	.075	.65			
72	A224	.075	.65			
73	A229	.03	.75			
74	A231	.2	1.			
75	A235	.03	.75			
76	A236	.2	.65			
77	A238	.2	.65			
78	A239	.03	1.			
79	A242	.1	1.			
80	A250	.075	1.			
81	A255	.03	.75			
82	A261	.2	1.			
83	A290	.05	1.			
84	A325	.25	.65			
85	A340	.0225	1.			
86	A341	.01125	.75			
87	A342	.0225	.75			
88	A353	.1	1.			
89	*END					
90	B102	.02808	1.0	.35714289.28571		1
91	B103	.02808	1.0	.35714289.28571		1
92	B104	.2016	1.0	.0	.7253885	1
93	B105	.2016	1.0	.0	.7253885	1
94	B106	.04572	.85	.061212	.009977	1
95	B108	.05328	.85	.0	5.44365	1
96	B109	.04572	.85	.0	5.9262	1
97	B110	.04572	.85	.0	5.9262	1
98	B111	.2016	1.0	.0	.7253885	1
99	B112	.2016	1.0	.0	.7253885	1
100	B113	.0414	.85	.0	5.9262	1
101	B114	.0414	.85	.0	5.9262	1
102	B115	.0414	.85	.0	5.9262	1
103	B334	.21384	.85	.0	.66672	1
104	B335	.017352	.85	.0	7.747388	1
105	B337	.21384	.85	.0	.66672	1
106	B338	.017352	.85	.0	7.747388	1
107	B351	.0864	.85	.0	2.10521	0
108	B352	.035424	.85	.0	4.72587	0
109	B347	.21384	.85	.0	.66672	0
110	B348	.017352	.85	.0	7.47388	0
111	B349	.21384	.85	.0	.66672	0
112	B350	.026280	.85	.0	5.61165	0
113	B343	.0864	.85	.0	2.36165	0

114	B344	.04392	.85 .0	4.7233	0
115	*END				

APPENDIX B - DATA CARDS PROVIDED FOR INDUSTRIAL AREA

1		2	2
2	H2011		
3	H2008		
4	*END		
5	H2030	.075	.65
6	H2033	.0075	.75
7	H2034	.2	.65
8	H2034	.1	.65
9	H2034	.1	.65
10	H2036	.075	.65
11	H2036	.0225	.65
12	H2038	.075	.5
13	H2040	.05	.65
14	H2041	.05	.65
15	H2043	.0225	.75
16	H2044	.05	.75
17	H2046	.075	.65
18	H2047	.075	.65
19	H2049	.015	.5
20	H2052	.03	.5
21	H2054	.0225	.75
22	H2056	.1	.65
23	H2058	.015	.75
24	H2059	.0075	.75
25	H2061	.015	.75
26	H2062	.0015	.5
27	H2064	.01125	.5
28	H2066	.03	.5
29	H2067	.03	.5
30	H2068	.03	.5
31	H2069	.01125	.5
32	H2072	.0045	.5
33	H2073	.03	.5
34	H2074	.03	.5
35	H2076	.03	.5
36	H2077	.01125	.5
37	H2084	.15	.65
38	H2085	.25	.65
39	H2093	.05	.75
40	H2094	.075	.75
41	H2170	.0015	.75
42	H2174	.0015	.75
43	H2176	.0015	.75
44	H2180	.0015	.75
45	H2182	.0015	.75
46	H2184	.00375	.75
47	H2186	.0075	.75
48	H2188	.05	.65
49	H2191	.01125	.75
50	H2193	.0075	.75
51	H2195	.01125	.65
52	H2208	.015	.5
53	H2217	.0045	.75
54	H2218	.0075	.75
55	H2220	.01	.75
56	H2222	.0025	.75

57	H2224	.0015	.75			
58	H2224	.0075	.75			
59	H2228	.05	.65			
60	H2230	.03	.65			
61	H2230	.05	.65			
62	H2233	.05	.65			
63	H2233	.05	.65			
64	H2236	.1	.65			
65	H2237	.15	.65			
66	H2237	.075	.65			
67	H2241	.01125	.65			
68	H2281	.1	.65			
69	H2283	.1	.65			
70	H2285	.1	.65			
71	H2299	.05	.5			
72	H2301	.075	.5			
73	H2303	.05	.5			
74	H2305	.0225	.5			
75	H2307	.05	.5			
76	H2309	.015	.5			
77	H2311	.015	.5			
78	H2313	.015	.5			
79	H2315	.03	.5			
80	H2317	.075	.5			
81	H2319	.05	.5			
82	H2321	.05	.5			
83	H2323	.03	.5			
84	H2325	.03	.5			
85	H2327	.03	.5			
86	H2329	.03	.5			
87	H2331	.05	.5			
88	H2333	.05	.5			
89	H2353	.03	.5			
90	H2355	.03	.5			
91	H2357	.03	.5			
92	H2359	.03	.5			
93	H2361	.03	.5			
94	H2363	.03	.5			
95	H2365	.03	.5			
96	H2367	.03	.5			
97	H2369	.05	.5			
98	H2371	.03	.5			
99	H2373	.03	.5			
100	H2375	.03	.5			
101	H2377	.05	.5			
102	H2379	.03	.5			
103	*END					
104	J2271	.0593	.85	.0	2.89284	1
105	J2271	.0593	.85	.0	2.89284	1
106	J2289	.0593	.85	.0	2.89284	1
107	J2350	.0824	.85	.0	2.69015	1
108	J2351	.0824	.85	.0	2.69015	1
109	J2352	.0748	.85	.0	2.67312	1
110	J2496	.0679	.85	.0	2.69015	1
111	J2497	.0679	.85	.0	2.69015	1
112	J2499	.0679	.85	.0	2.69015	1
113	J2500	.0679	.85	.0	2.69015	1
114	*END					